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FINAL TECHNICAL REPORT

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PRINCIPAL INVESTIGATOR: Gilda E. Ballester

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INSTITUTION: University of Michigan

PROJECT TITLE: "Archival Study of Energetic Processes in the Upper
Atmospheres of the Outer Planets"

SUMMARY OF PROJECT ACTIVITIES:

1. BRIEF DESCRIPTION OF THE PRIMARY OBJECTIVES AND SCOPE OF THE PROJECT:

- A) To compare IUE spectral observations of Jupiter's UV aurora in H-Lyman alpha (H-Lya) and H2 emissions with images of the UV aurora with HST to make more realistic interpretations of the IUE dataset.
- B) To use the limited spatial information in the IUE line-by-line spectra of the bright H-Lya line emission in the form of pseudo-monochromatic images at the IUE 3.5 arcsec resolution (Lya pseudo-images), to derive information on the emissions.
- C) Analysis of H2 spectra of Saturn's UV aurora to infer atmospheric level of auroral excitation from the methane absorption (color ratios).
- D) Analysis of a Uranus IUE dataset to determine periodicity in the emissions attributable to auroral emission fixed in magnetic longitude.
- E) Review of the results from IUE observations of the major planets, upper atmospheres and interactions with the planets magnetospheres.
- F) Analysis of IUE spectra of the UV emissions from Io to identify excitation processes and infer properties of the Io-torus-Jupiter system.

2. BRIEF DESCRIPTION OF THE FINDINGS:

A & B) IUE observations of Jupiter's north aurora made simultaneously with the HST WFPC2 camera (May 1994) were analyzed and compared by Ballester et al. (1996). It was found that the central meridian longitude (CML) dependence (in magnetic System III) of the peak brightness around 180 deg, was not due to an intrinsic enhancement at longitude 180 deg along the auroral oval as previously found from analysis of the IUE data, but partly an artifact. The IUE 3.5 arcsec PSF had been excluded in those previous analysis. Accounting for this, it was found that the aurora being more offset and inclined as seen from Earth at central meridian longitude 180 deg seemed brighter because of the blurring of the IUE, additional emission inside the auroral oval, and the consequent inclusion of more emission in the IUE aperture. The spatial information in the IUE Ly α pseudo-images, which covered a broader observing time than with HST, was also used together with the images to conclude that the emissions observed during a bright auroral event on Jupiter are confined to the magnetic local time dawn side. The combination of this dependence, in which the magnetic dawn can map to behind the limb of Jupiter, with the variable viewing of the aurora within the IUE aperture, produced an apparent shift in the emission peak at CML 240 deg, as had been previously inferred for a Dec 1990 auroral event observed with IUE (Prange, Zarka, Ballester and 6 other co-authors, J. Geophys. Res. Planets, 98, 18779, 1993). Revision of the 1990 data and of another event observed with IUE on July 1993 by Harris et al. (1995) also showed similar characteristics. These events are very energetic, depositing on the order of 400 ergs/cm²/sec into the atmosphere, and the consequences. Spectral information on the methane absorption of the H₂ emissions observed in these 3 events observed with IUE was used to estimate some properties regarding energy, dynamics and temporal constraints.

A parallel comparison of IUE observations and HST images obtained with the FOC by Prange et al. (1997a), and co-PI Harris, as well as PI Ballester were both substantial contributors to this work. One comparison set was for average auroral activity (February 1992), and the other of the IUE observations and FOC imaging during the July 1993 auroral event Harris et al 1995; Gerard, C. et al. Science 266, 1675, 1994). Similar results and conclusions were derived, in general, than by Ballester et al. (1996), so are not repeated here. One important result was to establish that, even with previous problems with the interpretation of the IUE data, the extensive IUE dataset is a valuable, and so far unique, measurement of the temporal behavior of the auroral activity on Jupiter. This was recently demonstrated with the dataset obtained of Jupiter's aurora encompassing almost a month in the last days of IUE operations in which Harris was a collaborator (Prange et al. 1997b; Prange, R. and T. Livengood, ESA SP-413, 29, 1998.). Comparison of the auroral intensities measured with IUE and in-situ data on the Jovian magnetic field obtained by the Galileo orbiter, showing enhanced auroral activity at times when the magnetic field was perturbed relative to a model.

B) Data on the H-Ly α bulge of Jupiter obtained on 1-2 June 1994 was analyzed. It was found, however, that there was insufficient information on the geocoronal H-Ly α background (due to unexpected high noise in one of the geocoronal exposures). The results were provided to collaborator Claude Emerich who was pursuing studies of Jupiter's Ly- α bulge with HST at the time, to show that the bulge had average brightness and apparently distribution in those dates (Emerich et al. 1996).

C) Although there was no time to conduct a full Saturn study, there was some simple analysis of one spectrum, of which the results were provided to collaborator Lotfi Ben Jaffel for his modeling of the upper

atmosphere of Saturn. Spatial information with the IUE line-by-line spectra was used to separate H₂ auroral emission from the equatorial latitudes. Chen et al. (J. Geophys. Res., 96, 17519, 1991) had recently published a disk-integrated albedo of Saturn in the far-UV and near-UV regime. It showed an apparent bump around 1500 Å and a relative depression around 1600 Å. With the line-by-line Saturn spectrum mentioned above, perusal of other IUE Saturn spectra, and articles in the IUE Newsletters were found to indicate that these features are from an artifact in the SWP camera, and seemed localized in a given portion of the line-by-line spectra. This was crucial information for the fitting of the Saturn's upper atmosphere albedo by our collaborator.

D) Analysis of Uranus H-Lya emission was not pursued since it was realized that there were some errors in the pointing of IUE satellite during the exposures, which should have smeared the emission substantially and made it unrecognizable above the geocoronal H-Lya background.

E) A review was written, Ballester (1998) of the IUE observations of the major planets, in terms of the phenomena observed relating to the upper atmosphere and interaction with the magnetosphere. This included the upper atmospheres and auroral processes on Jupiter, Saturn, and Uranus, as well as the Io plasma torus, and of Io's atmosphere and its interaction with the torus. This was presented at the IUE Symposium held last November at Sevilla, Spain. Ballester was co-author in another paper for this meeting by Ben Jaffel et al. (1998) reviewing the IUE observations of Jupiter's H-Lya bulge. Harris prepared a review of the IUE observations of the Shoemaker-Levy 9 comet crash onto Jupiter on 1994 (Harris 1998).

F) We have combined the results from the 1986, 1987 and 1988 IUE observations of Io's far-UV emissions in the region 1240-1950 Å taken with 14-hour exposures, with 1994-1996 HST observations mainly encompassing 1240-1500/1700 Å region with the GHRS, and a few with the FOS covering the 1600-1950 Å region, which provide information on a few minutes time scales. It has been determined that the bulk of Io's emissions do not agree with electron dissociative excitation of SO₂, nor electron-impact excitation of atomic oxygen (and perhaps atomic sulfur), when each one is the only excitation mechanism modeled. Observations of Io at east and west elongation observed with IUE and HST show large temporal variations. It was concluded that more than one excitation process must be present (Ballester et al. 1997). This is now evident from the different emission regions observed with Galileo, WFPC2, and STIS images of Io's emissions in the visible and far-UV. The emission mechanisms are yet to be identified. This work is mostly finished and is being written up for publication (Ballester et al. 1998). Analysis of IUE spectra of Io obtained after 1988 was started. An undergraduate student, Nick Larsen, was trained on the IUE data, and the data was retrieved and the first reduction cut was made (data needs special line-by-line reduction). More work is needed, however, and the student has now switched fields.

3. NAME AND DATE (OR ANTICIPATED DATE) OF THE PUBLICATION OF RESULTS:

A & B)

Harris, W.M., G.E. Ballester, R. Prange, "IUE observations of the declining phase of a bright auroral even in July 1993", Bull. Am. Astr. Soc., 27, 1149, 1995.

Ballester, G.E., J.T. Clarke, J.T. Trauger, W.M. Harris, and 16 co-authors, "Time-resolved observations of Jupiter's far-ultraviolet aurora", Science, 274, 409, 1996.

Prange, R., S. Maurice, W.M. Harris, D. Rego, and T. Livengood,

"Comparison of IUE and HST diagnostic of the Jovian auroral morphology", J. Geophys. Res., 102, 9289, 1997a.

Prange, R. and 9 co-authors including W. Harris, "Temporal survey of the Jovian auroral activity with IUE during Galileo G1/G23 orbit", Bull. Am. Astr. Soc., 29, 997, 1997b.

Another IUE and WFPC2 comparison is planned for the south aurora. Although no simultaneous IUE and imaging observations were made, WFPC2 has the provided the first full rotational coverage of Jupiter's south aurora (Clarke, J.T, G.E. Ballester, and several co-authors, J. Geophys. Res. Space, in press, 1998), which can be used to simulate the IUE observations, always done with the same pointing. Similar issues of intensity distribution and color ratio as in the north aurora as observed with IUE need to be resolved.

Emerich, C. and other co-authors including G.E. Ballester, Science, "Evidence of supersonic turbulence in the upper atmosphere of Jupiter", Science, 273, 1085, 1996.

C)

Contribution for Ben Jaffel, L. et al. (in preparation; 1998).

E)

Ballester, G.E., "Magnetospheric Interactions in the Major Planets", Proceedings of the Conference "Ultraviolet Astrophysics Beyond the IUE Final Archive", Sevilla, Spain, 11-14 November 1997, ESA SP-413, 21, 1998.

Harris, W.M., "IUE observations of the impact of comet Shoemaker-Levy 9 with Jupiter", ibid, page 37, 1998.

Ben Jaffel, L, G. Ballester, J.T. Clarke, C. Emerich, R. Gladstone and D. Rego, "The Lyman alpha bulge of Jupiter & and the auroral-equatorial regions coupling", ibid, page 53, 1998.

F)

Ballester, G. et al., "Io's far-ultraviolet emissions as observed with HST and IUE", Bull. Am. Astr. Soc., 29, 980, 1997.

Ballester, G. et al., "Spectroscopic and temporal characteristics of Io's far-UV emissions as observed with HST and IUE", manuscript in preparation for submission to the Astrophys. Journal, 1998.

If possible, a brief paper will be prepared to include all the IUE observations made of Io's UV emissions, to study temporal changes and compare the emissions east versus west of Jupiter, and compared to observations made with HST.

4. SUGGESTIONS AND ADDITIONAL COMMENTS:

Funding was used mainly for salary support for G.E. Ballester (which was extremely useful), for salary support for undergraduate student Nick Larsen to work on Io data, for computer maintenance, for publication costs of Ballester et al. (1996), for travel by W.M. Harris to 1995 DPS meeting and by G.E. Ballester for partial or full support to DPS meetings and a 1997 meeting at Flagstaff on Io.

PS - Copies of quoted papers are included in the package to the Naval Research Regional Representative in Chicago.